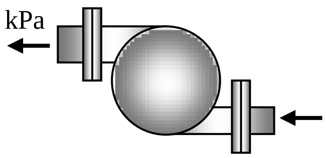
6-12 A water pump increases water pressure. The diameters of the inlet and exit openings are given. The velocity of the water at the inlet and outlet are to be determined.

Assumptions **1** Flow through the pump is steady. **2** The specific volume remains constant.

Properties The inlet state of water is compressed liquid. We approximate it as a saturated liquid at the given temperature. Then, at 15°C and 40°C, we have (Table A-4)

$$\left.\begin{array}{l} T = 15°\text{C} \\ x = 0 \end{array}\right\} \boldsymbol{v}_1 = 0.001001\ \text{m}^3/\text{kg}$$

$$\left.\begin{array}{l} T = 40°\text{C} \\ x = 0 \end{array}\right\} \boldsymbol{v}_1 = 0.001008\ \text{m}^3/\text{kg}$$



Analysis The velocity of the water at the inlet is

$$V_1 = \frac{\dot{m}\boldsymbol{v}_1}{A_1} = \frac{4\dot{m}\boldsymbol{v}_1}{\pi D_1^2} = \frac{4(0.5\ \text{kg/s})(0.001001\ \text{m}^3/\text{kg})}{\pi(0.01\ \text{m})^2} = \textbf{6.37 m/s}$$

Since the mass flow rate and the specific volume remains constant, the velocity at the pump exit is

$$V_2 = V_1\frac{A_1}{A_2} = V_1\left(\frac{D_1}{D_2}\right)^2 = (6.37\ \text{m/s})\left(\frac{0.01\ \text{m}}{0.015\ \text{m}}\right)^2 = \textbf{2.83 m/s}$$

Using the specific volume at 40°C, the water velocity at the inlet becomes

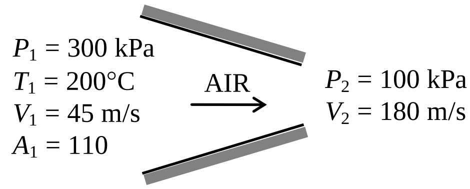
$$V_1 = \frac{\dot{m}\boldsymbol{v}_1}{A_1} = \frac{4\dot{m}\boldsymbol{v}_1}{\pi D_1^2} = \frac{4(0.5\ \text{kg/s})(0.001008\ \text{m}^3/\text{kg})}{\pi(0.01\ \text{m})^2} = \textbf{6.42 m/s}$$

which is a 0.8% increase in velocity.

6-28 Air is accelerated in a nozzle from 45 m/s to 180 m/s. The mass flow rate, the exit temperature, and the exit area of the nozzle are to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Air is an ideal gas with constant specific heats. **3** Potential energy changes are negligible. **4** The device is adiabatic and thus heat transfer is negligible. **5** There are no work interactions.

Properties The gas constant of air is 0.287 kPa.m^3/kg.K (Table A-1). The specific heat of air at the anticipated average temperature of 450 K is c_p = 1.02 kJ/kg.°C (Table A-2).



Analysis (*a*) There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. Using the ideal gas relation, the specific volume and the mass flow rate of air are determined to be

$$v_1 = \frac{RT_1}{P_1} = \frac{(0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(473 \text{ K})}{300 \text{ kPa}} = 0.4525 \text{ m}^3/\text{kg}$$

$$\dot{m} = \frac{1}{v_1} A_1 V_1 = \frac{1}{0.4525 \text{ m}^3/\text{kg}} (0.0110 \text{ m}^2)(45 \text{ m/s}) = \mathbf{1.094 \text{ kg/s}}$$

(*b*) We take nozzle as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{\text{system}}^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc. energies}}} = 0$$

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{m}(h_1 + V_1^2/2) = \dot{m}(h_2 + V_2^2/2) \quad (\text{since } \dot{Q} \cong \dot{W} \cong \Delta\text{pe} \cong 0)$$

$$0 = h_2 - h_1 + \frac{V_2^2 - V_1^2}{2} \longrightarrow 0 = c_{p,ave}(T_2 - T_1) + \frac{V_2^2 - V_1^2}{2}$$

Substituting,

$$0 = (1.02 \text{ kJ/kg} \cdot \text{K})(T_2 - 200^\circ \text{C}) + \frac{(180 \text{ m/s})^2 - (45 \text{ m/s})^2}{2} \left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2} \right)$$

It yields

T_2 = **185.2°C**

(*c*) The specific volume of air at the nozzle exit is

$$v_2 = \frac{RT_2}{P_2} = \frac{(0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(185.2 + 273 \text{ K})}{100 \text{ kPa}} = 1.315 \text{ m}^3/\text{kg}$$

$$\dot{m} = \frac{1}{v_2} A_2 V_2 \longrightarrow 1.094 \text{ kg/s} = \frac{1}{1.315 \text{ m}^3/\text{kg}} A_2 (180 \text{ m/s}) \rightarrow A_2 = 0.00799 \text{ m}^2 = \mathbf{79.9 \text{ cm}^2}$$

6-44 Saturated R-134a vapor is compressed to a specified state. The power input is given. The exit temperature is to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Kinetic and potential energy changes are negligible. **3** Heat transfer with the surroundings is negligible.

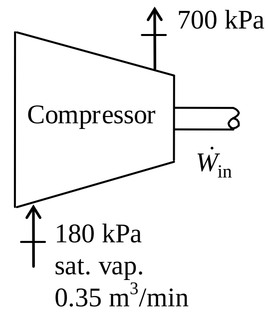
Analysis We take the compressor as the system, which is a control volume since mass crosses the boundary. Noting that one fluid stream enters and leaves the compressor, the energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{\text{system}}^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc. energies}}} = 0$$

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{W}_{\text{in}} + \dot{m}h_1 = \dot{m}h_2 \quad \text{(since } \Delta ke \cong \Delta \text{pe} \cong 0\text{)}$$

$$\dot{W}_{\text{in}} = \dot{m}(h_2 - h_2)$$



From R134a tables (Table A-12)

$$\left.\begin{array}{l} P_1 = 180 \text{ kPa} \\ x_1 = 0 \end{array}\right\} \begin{array}{l} h_1 = 242.86 \text{ kJ/kg} \\ v_1 = 0.1104 \text{ m}^3\text{/kg} \end{array}$$

The mass flow rate is

$$\dot{m} = \frac{\dot{V}_1}{v_1} = \frac{(0.35/60) \text{ m}^3\text{/s}}{0.1104 \text{ m}^3\text{/kg}} = 0.05283 \text{ kg/s}$$

Substituting for the exit enthalpy,

$$\dot{W}_{\text{in}} = \dot{m}(h_2 - h_1)$$

$$2.35 \text{ kW} = (0.05283 \text{ kg/s})(h_2 - 242.86)\text{kJ/kg} \longrightarrow h_2 = 287.34 \text{ kJ/kg}$$

From Table A-13,

$$\left.\begin{array}{l} P_2 = 700 \text{ kPa} \\ h_2 = 287.34 \text{ kJ/kg} \end{array}\right\} T_2 = \mathbf{48.8^\circ C}$$

6-60 Steam is throttled from a specified pressure to a specified state. The quality at the inlet is to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Kinetic and potential energy changes are negligible. **3** Heat transfer to or from the fluid is negligible. **4** There are no work interactions involved.

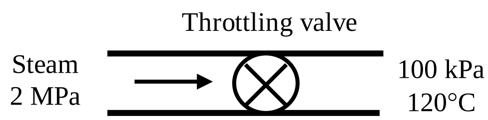
Analysis There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take the throttling valve as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

$$\dot{E}_{\text{in}} - \dot{E}_{\text{out}} = \Delta\dot{E}_{\text{system}}^{\nearrow 0 \text{ (steady)}} = 0$$

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{m}h_1 = \dot{m}h_2$$

$$h_1 = h_2$$



Since $\dot{Q} \cong \dot{W} = \Delta\text{ke} \cong \Delta\text{pe} \cong 0$.

The enthalpy of steam at the exit is (Table A-6),

$$\left.\begin{array}{l} P_2 = 100\text{ kPa} \\ T_2 = 120°\text{C} \end{array}\right\} h_2 = 2716.1\text{ kJ/kg}$$

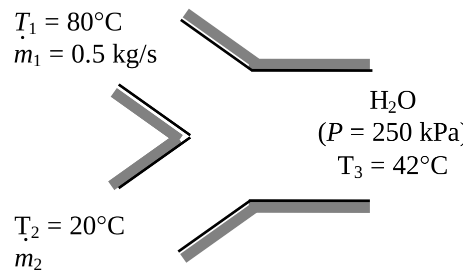
The quality of the steam at the inlet is (Table A-5)

$$\left.\begin{array}{l} P_1 = 2000\text{ kPa} \\ h_1 = h_2 = 2716.1\text{ kJ/kg} \end{array}\right\} x_1 = \frac{h_2 - h_f}{h_{fg}} = \frac{2716.1 - 908.47}{1889.8} = \mathbf{0.957}$$

6-69 A hot water stream is mixed with a cold water stream. For a specified mixture temperature, the mass flow rate of cold water is to be determined.

Assumptions **1** Steady operating conditions exist. **2** The mixing chamber is well-insulated so that heat loss to the surroundings is negligible. **3** Changes in the kinetic and potential energies of fluid streams are negligible. **4** Fluid properties are constant. **5** There are no work interactions.

Properties Noting that $T < T_{\text{sat @ 250 kPa}} = 127.41°\text{C}$, the water in all three streams exists as a compressed liquid, which can be approximated as a saturated liquid at the given temperature. Thus,



$$h_1 \cong h_{f\,@\,80°\text{C}} = 335.02 \text{ kJ/kg}$$

$$h_2 \cong h_{f\,@\,20°\text{C}} = 83.915 \text{ kJ/kg}$$

$$h_3 \cong h_{f\,@\,42°\text{C}} = 175.90 \text{ kJ/kg}$$

Analysis We take the mixing chamber as the system, which is a control volume. The mass and energy balances for this steady-flow system can be expressed in the rate form as

Mass balance:

$$\dot{m}_{\text{in}} - \dot{m}_{\text{out}} = \Delta\dot{m}_{\text{system}}^{\nearrow 0 \text{ (steady)}} = 0 \longrightarrow \dot{m}_1 + \dot{m}_2 = \dot{m}_3$$

Energy balance:

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta\dot{E}_{\text{system}}^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc. energies}}} = 0$$

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 h_3 \quad (\text{since } \dot{Q} = \dot{W} = \Delta\text{ke} \cong \Delta\text{pe} \cong 0)$$

Combining the two relations and solving for $\dot{m}_2$ gives

$$\dot{m}_1 h_1 + \dot{m}_2 h_2 = (\dot{m}_1 + \dot{m}_2) h_3$$

$$\dot{m}_2 = \frac{h_1 - h_3}{h_3 - h_2} \dot{m}_1$$

Substituting, the mass flow rate of cold water stream is determined to be

$$\dot{m}_2 = \frac{(335.02 - 175.90) \text{ kJ/kg}}{(175.90 - 83.915) \text{ kJ/kg}} (0.5 \text{ kg/s}) = \mathbf{0.865 \text{ kg/s}}$$

6-83 Refrigerant-134a is condensed in a condenser by cooling water. The rate of heat transfer to the water and the mass flow rate of water are to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Kinetic and potential energy changes are negligible. **3** There are no work and heat interactions between the condenser and the surroundings.

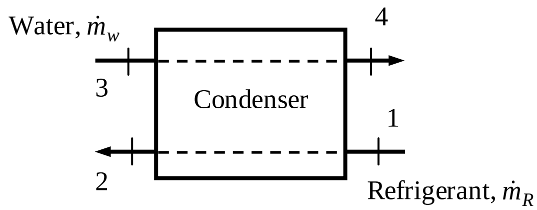
Analysis We take the condenser as the system, which is a control volume. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{\text{system}}^{\nearrow 0\ \text{(steady)}}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc. energies}}} = 0$$

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{m}_R h_1 + \dot{m}_w h_3 = \dot{m}_R h_2 + \dot{m}_w h_4$$

$$\dot{m}_R (h_1 - h_2) = \dot{m}_w (h_4 - h_3) = \dot{m}_w c_p (T_4 - T_3)$$



If we take the refrigerant as the system, the energy balance can be written as

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{\text{system}}^{\nearrow 0\ \text{(steady)}}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc. energies}}} = 0$$

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{m}_R h_1 = \dot{m}_R h_2 + \dot{Q}_{\text{out}}$$

$$\dot{Q}_{\text{out}} = \dot{m}_R (h_1 - h_2)$$

(a) The properties of refrigerant at the inlet and exit states of the condenser are (from Tables A-11 through A-13)

$$\left.\begin{array}{l} P_1 = 1200\ \text{kPa} \\ T_1 = 85°\text{C} \end{array}\right\} h_1 = 316.73\ \text{kJ/kg}$$

$$\left.\begin{array}{l} P_2 = 1200\ \text{kPa} \\ T_2 = T_{\text{sat @ 1200 kPa}} - \Delta T_{\text{subcool}} = 46.3 - 6.3 = 40°\text{C} \end{array}\right\} h_2 \cong h_{f\ @\ 40°\text{C}} = 108.26\ \text{kJ/kg}$$

The rate of heat rejected to the water is

$$\dot{Q}_{\text{out}} = \dot{m}_R (h_1 - h_2) = (0.042\ \text{kg/s})(316.73 - 108.26)\text{kJ/kg} = 8.76\ \text{kW} = \mathbf{525\ kJ/min}$$

(b) The mass flow rate of water can be determined from the energy balance on the condenser:

$$\dot{Q}_{\text{out}} = \dot{m}_w c_p \Delta T_w$$

$$8.76\ \text{kW} = \dot{m}_w (4.18\ \text{kJ/kg} \cdot °\text{C})(12°\text{C})$$

$$\dot{m}_w = 0.175\ \text{kg/s} = \mathbf{10.5\ kg/min}$$

The specific heat of water is taken as 4.18 kJ/kg·°C (Table A-3).